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REDETERMINATION OF FLUXES FOR IRAS GALAXIES

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One of the most important discoveries of the Infrared Astronomical Satellite (*IRAS*) has been the detection of about 20,000 galaxies with $60\mu m$ fluxes above 0.5 Jy. From the observational point of view, the *IRAS* galaxies are ideal tracers of density, since they are homogeneously detected over most of the sky, and their fluxes are unaffected by galactic extinction. The nearby universe has now been mapped by the *IRAS* galaxies to a distance $\sim 200h^{-1}$ Mpc for $|b| > 5°$. The ability to map down to such low galactic latitudes has proven to be particularly important, since some of the most important nearby large-scale structures, such as the Great Attractor, the Perseus–Pisces region, and the Shapley concentration, all lie there.

I have been active in this field since its inception, first showing on the basis of positions and fluxes that the *IRAS* dipole was aligned, within the errors, with the dipole anisotropy of the microwave background radiation (Yahil, Walker, & Rowan-Robinson 1986), and then initiating an extensive, multi-year, redshift survey in collaboration with M. Davis, K. Fisher, J. Huchra, & M. Strauss, which provided the 3–d density maps. (A parallel effort has been undertaken by a British-Canadian collaboration known as QDOT.)

The sample for the U. S. *IRAS* redshift survey was initially defined using fluxes from the Point Source Catalog (PSC), with ADDSCANs performed on a subset of the sample to improve the fluxes. In the conversion from galaxy counts to density, the flux error was assumed to be a constant fraction of the flux. This was a good initial procedure, and the results speak for themselves. But as we move on to confront the derived density field more closely with theory and with other data, we need to remove systematic errors that were glossed over before. The major areas of concern are the underestimate of fluxes of extended nearby galaxies, noise due to confusion at low galactic latitude, and systematic errors at large distances.

In this project I seek to reduce the systematic errors in the derived *IRAS* density field by: (1) obtaining realistic unbiased measurements of fluxes for extended nearby sources, whose fluxes are underestimated by the point source template, (2) taking account of confusion with other sources in the beam, primarily foreground cirrus in our own Galaxy, (3) recognizing that flux errors are position and flux dependent, particularly at lower galactic latitudes, and obtaining an individual estimate of flux error for each source, and (4) determining the completeness of the catalog as a function of both flux and position.

There are errors in the *IRAS* density field due to four effects (Davis, Strauss, & Yahil 1991; Strauss *et al.* 1992a): (1) sampling (shot) noise due to the finite number of galaxies, (2) uncertainties in the derived selection function and average density, (3) uncertainties in the correction for peculiar velocities, and (4) regions of the sky not covered by the survey.

The largest *statistical* error is due to sampling noise (Dekel *et al.* 1993). This noise can be reduced somewhat by increasing the sample size (the QDOT project). Here I am concerned with *systematic* errors, which can be traced primarily to flux errors, affecting both the sample definition and the conversion from galaxy number counts to spatial densities via the selection function.

First, the fluxes of extended galaxies, e.g., the ones in the Local Supercluster, are systematically underestimated by the *IRAS* Point Source Catalog (PSC). While we have attempted to compensate for this error by obtaining ADDSCAN/SCANPI fluxes for a significant fraction of our sources, we did not ADDSCAN all of them, and the criteria by which sources were chosen for ADDSCAN were not always optimal. We are particularly concerned about sources whose PSC fluxes are below the 1.2 Jy limit, hence were not included in our sample, but would be if the SCANPI flux were available and above 1.2 Jy.

Yahil *et al.* (1991) describe our method for finding the selection function. It is computed at each distance as an integral over the luminosity function, as truncated by the flux limit. But we select galaxies on the basis of their *measured* luminosities, not the true ones. Hence the relevant luminosity function is a convolution of the true luminosity function and the flux error function. We have so far taken the flux error to be proportional to flux (*IRAS* Explanatory Supplement 1988, Table VII.D.2). In that case, the convolved luminosity function is independent of distance, and one need never consider the true luminosity function (Strauss, Yahil, & Davis 1991).

We have found, however, that the proportionality of flux error to flux breaks down at low fluxes, first leveling off with decreasing flux, and then even rising somewhat. Failure to account for this effect in the selection function leads to a systematic error in the derived density as a function of distance which mimics evolution (Fisher *et al.* 1992).

The situation is even worse, because a non-negligible fraction of the sources are confused by the presence of another source within the beam, usually foreground cirrus. Neither the PSC nor the SCANPI fluxes fully account for this confusion, as detailed inspections of problematic ADDSCANs have shown.

Needless to say, confusion becomes more severe closer to the galactic plane, and the flux error function is therefore broader there. This introduces a directional bias, in addition to the distance bias. Unfortunately some of the most interesting nearby large-scale structures, such as the Great Attractor, the Perseus–Pisces region, and the Shapley concentration, all lie at low galactic latitudes.

In view of the above difficulties this project redetermines the fluxes of *all* the *IRAS* galaxies. First, the most accurate unbiased flux is sought for any source that may be a galaxy. Proper account is taken both of the possible finite extent of the galaxy (relative to the beam), and confusion with other source(s). If the confusing source(s) can not be "fitted away", the target source should at least be flagged for more detailed investigation. Secondly, a realistic flux error distribution is assigned to each source, so that the selection function can reliably be computed on a per source basis as a convolution of the true luminosity function and the flux error function. Finally, for the sake of deeper samples, such as the QDOT surveys, the completeness of the catalog should be studied as a function of direction.

When M. Strauss and I first approached *IPAC* with a proposal for a comprehensive evaluation of extragalactic *IRAS* fluxes, it turned out that *IPAC* wanted to generate an extragalactic catalog down to $|b| = 20°$ (EGCAT), and we sought to combine our efforts. We quickly agreed to define a sample according to the following rules: (1) all sources, $|b| > 20°$, with $f_{60} > 0.4$ Jy in the Faint Source Database, no color criterion applied (25,762 sources); (2) all sources, $5° < |b| < 20°$, with $f_{60} > 0.4$ Jy in the Faint Source Database, and which satisfy ${f_{60}}^2 > f_{12}f_{25}$ and $f_{100}/f_{60} \leq 5$ (23,353 sources);[1] (3) all galaxies in the UGC, ESO, and ESGC galaxy catalogs with quoted optical diameter $\geq 2'$ and with $|b| > 20°$. We left open the possibility of extending the project at low galactic latitudes, by removing the second flux condition, if results from the project as currently defined justified it.

It became clear from extensive discussions at the time that it would be very man-power expensive to change any of the basic *IPAC* software. Instead, we should use the existing software, and perform post-processing analysis on the output obtained from *IPAC*İt was decided that *IPAC* would ADDSCAN all the sample sources and we would fit the ADDSCANs. I wrote a software package which does this fits a broadened instrumental point source template to the ADDSCANs in the Fourier transform k-space, instead of in the original scan space. The code, which I allow to be distributed freely, is available via *IPAC*İt is very robust and has fitted all the sample sources without a hitch. It is also very efficient, processing 1000 sources per hour on a DECstation 3100 workstation, all the way from the input *IPAC* ADDSCAN/SCANPI tape to the final output file.

In the last year I have expanded the fit to account for asymmetric flux errors. For most of the sources I found the errors to be quite symmetric, as expected for a tight fit, where the χ^2 is parabolic near the minimum. A fraction of the sources, however, had poorer fits, and showed skewness in the χ^2 distribution. I evaluated the points $\chi^2_{\rm min} + 1$ on both sides of the minimum, thus obtaining independent positive and negative flux errors.

Careful inspection of many ADDSCANs showed that there is considerable confusion,

[1]The former flux criterion effectively eliminates stars, while leaving cirrus and some other galactic sources. The second condition was added in order to discriminate against cirrus point sources, although it also discriminates against low-luminosity galaxies.

particularly at low galactic latitude, which is unlikely to be removed by any 1-d analysis. My student, Paul Mancinelli, and I have therefore begun a systematic 2-d analysis. As a first step we obtained from *IPAC* the entire *IRAS* level-1 archive and snipped out of it fields of $20' \times 20'$ around each of our 50,000 sources. This work took 1.5 CPU months, and considerably longer real time. We then adapted the *IPAC* HIRES software to our DEC Alpha workstation. (Unfortunately the *IPAC* software was machine-specific to a Sun workstation.) Having done that, we inspected a large number of HIRES images, both in and out of the plane.

We found that the software is not completely able to remove striping effects in the data, and we are very concerned about the photometric accuracy of the structure that is seen after the maximum correlation mechanism is turned on. We suspect that some of the flux of the sources is "bled away" to the surrounding, resulting in an underestimate of flux. We are therefore now looking into alternative image reconstruction methods. The most promising appears to be the pixon Bayesian image reconstruction technique (Puetter 1994, and references therein). This method gave by far the best results for the reconstruction of the whirlpool galaxy M51. It has also shown spectacular reconstruction of satellite X-ray images of solar flares, as well as ground-based images of the nucleus of the elliptical galaxy M87, observed with better resolution by the Hubble Space Telescope. We are working with Puetter to improve and automate his technique, in order to be able to apply it with reasonable computing effort to our large number of sources.

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